Atomic and nuclear physics

X-ray physics

X-ray energy spectroscopy

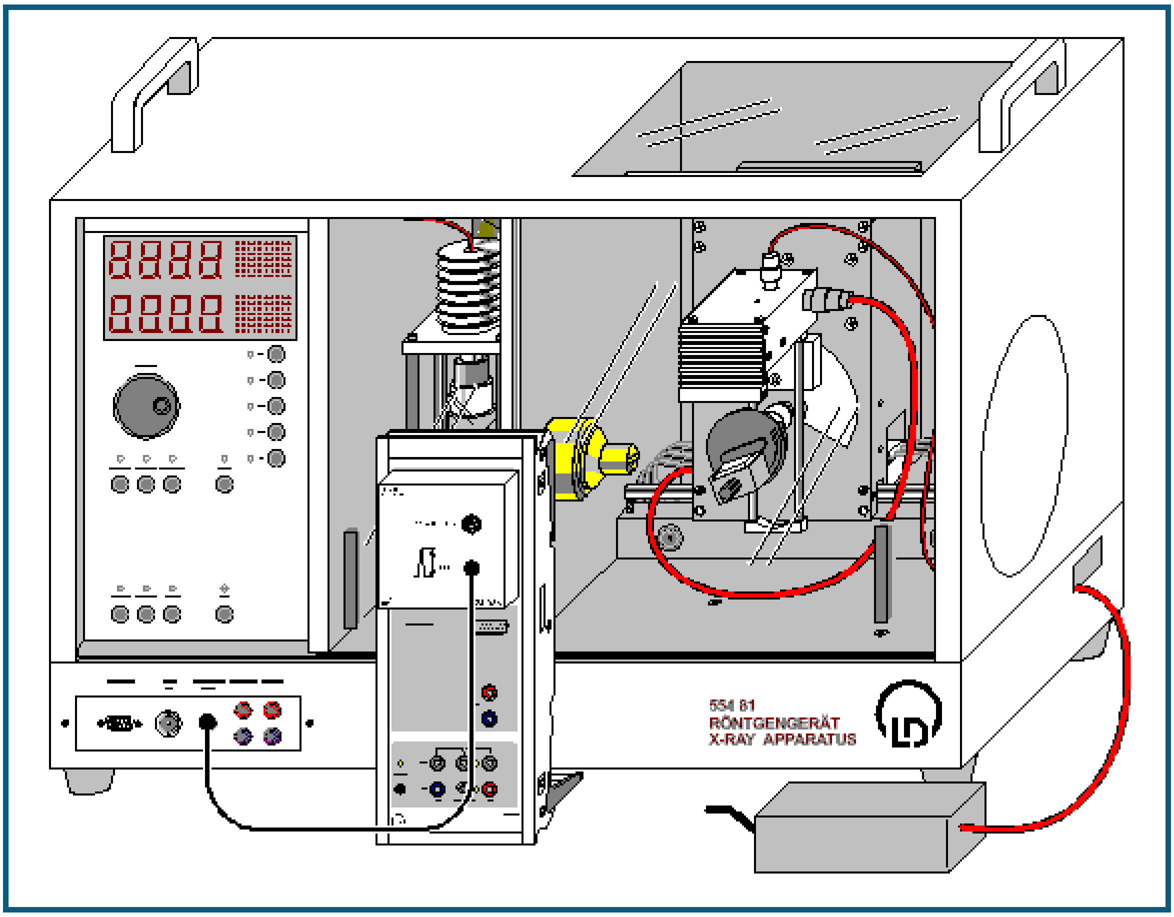
Investigation of the characteristic spectra as a function of the element's atomic number: K-lines

Description from CASSY Lab 2

For loading examples and settings, please use the CASSY Lab 2 help.

CASSY Lab 2 (2013-06-07)

Moseley's law (K-line x-ray fluorescence)



can also be carried out with Pocket-CASSY

Safety notes

The X-ray apparatus fulfils all regulations on the design of an X-ray apparatus and fully protected device for instructional use and is type approved for school use in Germany (BfS 05/07 V/Sch RöV or NW 807 / 97 Rö).

The built-in protective and shielding fixtures reduce the dose rate outside the X-ray apparatus to less than 1 µSv/h, which is of the order of magnitude of the natural background radiation.

- Before putting the X-ray apparatus into operation, inspect it for damage and check whether the voltage is switched off when the sliding doors are opened (See instruction sheet of the X-ray apparatus).
- Protect the X-ray apparatus against access by unauthorized persons.

Avoid overheating of the anode in the X-ray tube.

- When switching the X-ray apparatus on, check whether the ventilator in the tube chamber starts rotating.

The goniometer is positioned solely by means of electric stepper motors.

- Do not block the target arm and the sensor arm of the goniometer and do not use force to move them.

When handling heavy metals or allergen substances from the target set, observe their operating instructions.

Experiment description

X-ray fluorescence occurs when electrons are knocked out of the inner shells of an atom through x-ray radiation. The atom ionized in this way then has a vacancy (electron hole) in a lower shell which previously had been full. These electron holes can be filled with electrons from other, less strongly bound shells of the atom: e.g. the K-shell can be closed by the transition of an electron from the L-shell. Such a transition is connected with the emission of a photon. This radiation has only particular discrete photon energies corresponding to the energy difference of the levels involved, and it is characteristic for every chemical element.

The designations of the characteristic x-ray lines are a combination of the symbol for the electron shell (K, L, M etc.) and a Greek letter (α, β, γ, etc.). The electron shell being referred to is the one which was ionized before the electron transition. For example, the designation K_α-line describes the transition from the L-shell into the K-shell, K_β-line refers to the transition from the M-shell to the K-shell. The L_α- and L_β-lines refer to the transitions from the M-shell and the N-shell to the L-shell.

For the energies E of the characteristic lines Moseley discovered in 1913 the following law

$$\sqrt{\frac{E}{Ry}} = (Z-\sigma)\sqrt{\frac{1}{n_1^2}-\frac{1}{n_2^2}}$$

with the atomic number Z, the screening constant σ, the constant $Ry = m_e e^4/8\varepsilon_0^2 h^2 = 13.6$ eV and the main quantum numbers n_1 and n_2 for the electron shells involved ($n_1 < n_2$).

In the experiment, the energies of the K_α and K_β-lines for Ti, Fe, Ni, Cu, Zn, Zr, Mo and Ag are determined, Moseley's law is confirmed and the screening constants σ_α and σ_β are determined.

Equipment list

1	Sensor-CASSY	524 010 or 524 013
1	CASSY Lab 2	524 220
1	MCA box	524 058
1	X-ray apparatus with x-ray tube Mo	554 801 or 554 811
1	Target set for K-line fluorescence	554 844
1	X-ray energy detector	559 938
1	HF cable, 1 m	501 02
1	PC with Windows XP/Vista/7/8	

Experiment setup (see drawing)

- Guide the connection cable for the table-top power supply through the empty channel of the x-ray apparatus and connect it to the mini-DIN socket of the x-ray energy detector.
- Secure the sensor holder with the mounted x-ray energy detector in the goniometer sensor arm
- Connect the signal output of the x-ray energy detector to the BNC socket SIGNAL IN of the x-ray apparatus by means of the BNC cable included
- Feed enough connection cable through to make complete movement of the sensor arm possible
- Press the SENSOR button and set the sensor angle with the rotary adjuster ADJUST manually to 90°
- Set the distances between the slit aperture of the collimator and the axis of rotation as well as between the axis of rotation and the window of the x-ray energy detector both to 5 to 6 cm
- Press the TARGET button and adjust the target angle manually using the rotary button ADJUST to 45°.
- Connect Sensor-CASSY to the computer and connect the MCA box
- Connect the SIGNAL OUT output in the connection panel of the x-ray apparatus to the MCA box by means of the BNC cable.

Carrying out the experiment

- Load settings
- Connect the table-top power supply to the mains (after approx. 2 min the LED will glow green and the x-ray energy detector will be ready for use)
- Place the titanium (Ti) target from the target set for K-lines fluorescence onto the target table
- Set the tube high voltage U = 35 kV, emission current I = 1.00 mA and switch the high voltage on
- Start the spectrum recording with
- Then record the spectra for the other targets (Fe, Ni, Cu, Zn, Zr, Mo and Ag) in the target set for K-lines fluorescence

Energy calibration

The energy calibration of the spectra is made using the K_α-lines of iron (Fe) and molybdenum (Mo).

- Open in the Settings EA (right mouse button) the Energy calibration, select **Global for all spectra of this input** and enter on the right-hand side the energies of the Fe K_α-line (6.40 keV) and of the Mo K_α-line (17.48 keV).
- In the context menu of the diagram select Calculate peak center, mark the Fe K_α-line (2nd spectrum) and enter the result in the left-hand side of the Energy calibration (e.g. with drag & drop from the status line)
- Then determine the center of the Mo K_α-line (7th spectrum) and also enter the result on the left-hand side
- Switch the display to energy (e.g. with Drag & Drop of E_A into the diagram)

Evaluation

As the atomic number Z increases the energy of the characteristic lines also increases and so does the separation between the α- and the β-component in the K spectral series. For a quantitative analysis, the energies of the individual lines can be determined:

- Select spectrum in the diagram
- In the context menu choose Set Marker → Vertical line and mark approximately the positions of the K_α and K_β-line with two vertical lines.
- In the context menu of the diagram select Fit Function → Gaussians of equal width and mark the area of the desired peak (also mark sufficient background!)
- Read the determined peak positions from the status line and enter them together with the atomic numbers Z of Ti (Z=22), Fe (Z=26), Ni (Z=28), Cu (Z=29), Zn (Z=30), Zr (Z=40), Mo (Z=42) and Ag (Z=47) into the **Energy** diagram (click with mouse) (e.g. by drag & drop from the status line)

For each line, the expression √E/Ry is automatically calculated and plotted in the **Moseley** diagram as a function of the atomic number Z. The same applies to the screening constants σ_α and σ_β and the **Screening** diagram.

In the **Moseley** diagram, by a free fit with the formula (x-1)*sqr(3/4), the theoretical line for the K_α-line can be entered, which corresponds well to the measured values.

The **Screening** diagram shows for the K_α-line that the deviation from the theoretically expected σ_α=1 grows with increasing atomic number Z. This is explained by the fact that the influence of the external electrons increases as the number of electrons increases.

The screening constants σ_β for the K_β-lines have a value σ_β≈2 which indicates, as expected, a stronger effective screening of the nucleus charge for the electron transitions from the higher level n_2=3.